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"Multi-agent System for Rapid TST Decision Support"

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14. ABSTRACT
Our adversaries understand the need to limit their exposure time to preying USAF eyes. The enemy hides, exposes only during the briefest of time and then hides again. As the enemy adapts to our technology and finds methods to minimize their exposure, the F2T2EA ?kill chain? had to be compressed from hours, to seconds. Obvious impediments to fast Time Sensitive Targets (TST) engagement are aircraft strike time and administrative delay in the kill chain. 21st Century Systems, Incorporated is developing RPAT Technicians to compress the F2T2EA timeline for support to near-instantaneous planning assessment and airborne weapons assignment for a team distributed in a ground control center and airborne control platform. Reactive planning against TSTs requires prior lists of ?what-if? and ?what-to-do? which will naturally accelerate the manual decision process. RPAT Technicians work inside the human decision loop to support the need for immediate answers. The key component of the system is the Decision Agent for Rapid TST, or DART. DARTs encapsulate human and pre-calculated knowledge in order to provide rapid, low-cost recommendations during emerging events. Supporting Technician agents interface with information systems and gather the data needed by DARTs for generating recommendations.

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Multi-agent System for Rapid TST Decision Support

Abstract

Our adversaries understand the need to limit their exposure time to preying USAF eyes. The enemy hides, exposes only during the briefest of time and then hides again. As the enemy adapts to our technology and finds methods to minimize their exposure, the F2T2EA "kill chain" had to be compressed from hours, to seconds. Obvious impediments to fast Time Sensitive Targets (TST) engagement are aircraft strike time and administrative delay in the kill chain. 21st Century Systems, Incorporated is developing RPAT Technicians to compress the F2T2EA timeline for support to near-instantaneous planning assessment and airborne weapons assignment for a team distributed in a ground control center and airborne control platform. Reactive planning against TSTs requires prior lists of "what-if" and "what-to-do" which will naturally accelerate the manual decision process. RPAT Technicians work inside the human decision loop to support the need for immediate answers. The key component of the system is the Decision Agent for Rapid TST, or DART. DARTs encapsulate human and pre-calculated knowledge in order to provide rapid, low-cost recommendations during emerging events. Supporting Technician agents interface with information systems and gather the data needed by DARTs for generating recommendations.

Keywords: Time-Sensitive Target, Kill-Chain Decision Process, F2T2EA, Course of Action, Intelligent Agent, Situational awareness, Dynamic contingency allocation

Introduction

The enemy knows to limit their exposure and reveals itself only during the briefest of action time, and moves away to conceal. In the April 2003 report "*Operation IRAQI FREEDOM – By The Numbers,*" Lt. Gen. Moseley, the USAF Commander of Combined Forces Air Component Command (CFACC), gave the assessment of Operation Iraqi Freedom (OIF) operations containing information about time sensitive targets (TST) and dynamic targets. Due to the fleeting nature of some targets and serious consequences of weapons of mass destruction (WMD) use, they developed a special capability to Find, Fix, Track, Target, Engage for these critical targets and Assess the attack, i.e., the functional F2T2EA "kill chain." Three types of targets were defined as TSTs: Leadership (50), WMD (102) and Terrorists (4); the number in parenthesis being the reported missions executed as a TST. The CFACC also recognized some highly mobile and otherwise important targets as well that could be attacked using the same tools. These were called dynamic targets and 688 were prosecuted using re-rolled airborne aircraft though the report does not indicate mission success.

When forces (people) are close to the battlespace, they are more in tune with rapid changes than when far removed. One might argue that troops need not be put in harm's way near the battle since increases in information technology allow warfighters to remotely fight from the homeland in a virtual environment. Perhaps, but the human

element divorced from the fray may not react the same way as one on the front lines. Deploy the minimum personnel necessary and distribute the decision process with those located away from the front. The current AWACS mission crew sizing is 13 to 19 and there is an avionics modernization program to include on-scene C2 battle management. Although a future AWACS upgrade is looking to take crew off the aircraft (Mission Crew to Ground), other programs like the E-10 want crew on the platform. The E-10 Multi-Sensor Command and Control Aircraft (MC2A) will provide key battle management command and control and is expected to be a central element in the Air Force's Command and Control Constellation. Full automation of the decision process is not in this decade. Unknown targets to the air tasking order (ATO), out-of-sequence flights in the controlled airspace, unknown collaterals, use of lethal force, CNN nightly news, etc. will complicate the decision process beyond practical limits of reliable, dependable USAF operations. The process of re-planning quickly must be within the target's vulnerability window, but with minimum onboard mission crew. Of course, without instantaneous access, wide-band data links, secure transmissions, and so on, it would not be possible to share the fast decision process between a ground center and a flying command post. The future will bring new multi-media high speed communication networks.

How fast a decision process is needed? The time interval metric, say, from a dynamic targeting cell fix, selecting the course of action (COA), to a pilot's eyes on target (or a UAV's sensor/weapon) is to be measured in *seconds*. An obvious impediment to fast TST engagement is that aircraft must travel to and strike the target before it disappears from view. This problem may be ameliorated in the future by more unmanned aircraft with sensors *and* weapons. Not so obvious though, but just as important, is the administrative delay of the kill chain process. TST operations will require fast target approval with known rules of engagement. The way to do so is to have on hand a long list of potential targets, air threats, sensitive collateral damage areas, escalation rules, JAG rules, ROEs, etc. A validated target is unexpectedly spotted and judged to be a short dwell time and nearing an area on the "no-hit" list – a go for a responsive airborne divert? The short decision time requires automated support.

However, attempting to automate this process leads to many more issues. What is the information available and where is it located for decisions concerning the TST alerting of identified target, target tracking, COA evaluation, and asset assignment for engagement (parts of F2T2EA)? How will the time-critical information be distributed? What information is needed by team members for decision making? AOC elements have computational resources, such as TBMCS (Theater Battle Management Core Systems), access to databases, and expert members (e.g., Intel, legal, military leaders). The onboard elements are limited in processing capability and operator's time, but do have the on-scene action with direct links to assign airborne weapons.

In order to address this, the Air Force released an SBIR solicitation AF071-089 "Reactive Planning Against TSTs (RPAT)." The remainder of this paper summarizes the 21st Century Systems, Inc. Phase I efforts in response to this solicitation.

Initial Work

System Design

In order to address the problem of TST prosecution time, we envisioned RPAT Technicians to be a suite of ground and flight segment products operating in a distributed capacity in the AOC and on the airborne platform systems. The flight segment consists of the primary user interfaces for the action point, the time and location where final, lethal decisions are made. Here, the weapons directors direct available assets against pre-assigned targets as well as TSTs. So, the flight segment supports weapons officers when TSTs pop up by gathering cogent information and providing recommended COAs including weapon-target pairing and platform assignment. This can occur in real-time due to pre-processing in the ground segment. Specifically, the ground segment has significantly larger access to both computational resources and information sources which allows pre-processing of many calculations that have such requirements.

Supporting Technician agents are deployed in the theater AOC (operations, training, and simulations) and flying platform(s) and are running continuously whether a TST alert is being processed or not. Various Technicians are located at each and every TST member's console and workstation, constantly monitoring the unfolding situation and updating accordingly. These hierarchical sets of intelligent agents act as technicians in support of human team members. Each agent type is characterized by the domain support needs, the span of available data resources available. Based on a human-derived TST list, analyst-type technicians will scour the network data sources and will use multiple data fusion algorithms for keeping TST situational awareness within the flying platform's area of responsibility. Back-door technicians will perform behind-the-scenes "what-if" COAs.

At the action point (for example, support of a Weapons Director making aircraft TST assignment) is the Decision Agent for Rapid TST, or DART. The DART is a Technician that is central to our concept for rapid reaction to TSTs. Each DART, one or more for each type of TST on the list, is a fast-acting rule-based decision support for assignment recommendation.

Each DART Technician is created by an agent factory process in the AOC environment, and all recently created DARTs are periodically uploaded to the appropriate flying platforms (e.g., AWACS) via the RPAT Technicians' mobile agent protocol. Each DART is an agent which encapsulates the decisions and situation contingencies of a specific target (e.g., Bin Laden) or target type (e.g., a mobile SCUD platform). The contingencies are the set of variable conditions that must satisfy limit sets in order that the DART decision is actualized. When running onboard a flying platform, each DART Technician seeks to evaluate its contingency set and to keep it current. For example, if "visibility must be 3 miles or better" is a contingency then the DART periodically requests the value for visibility. Such evaluations may be accomplished via service requests to other Technicians within the virtual TST cell. DARTs use the idea of "partial program evaluation" to maintain their current state. The purpose of a DART is to provide as rapid
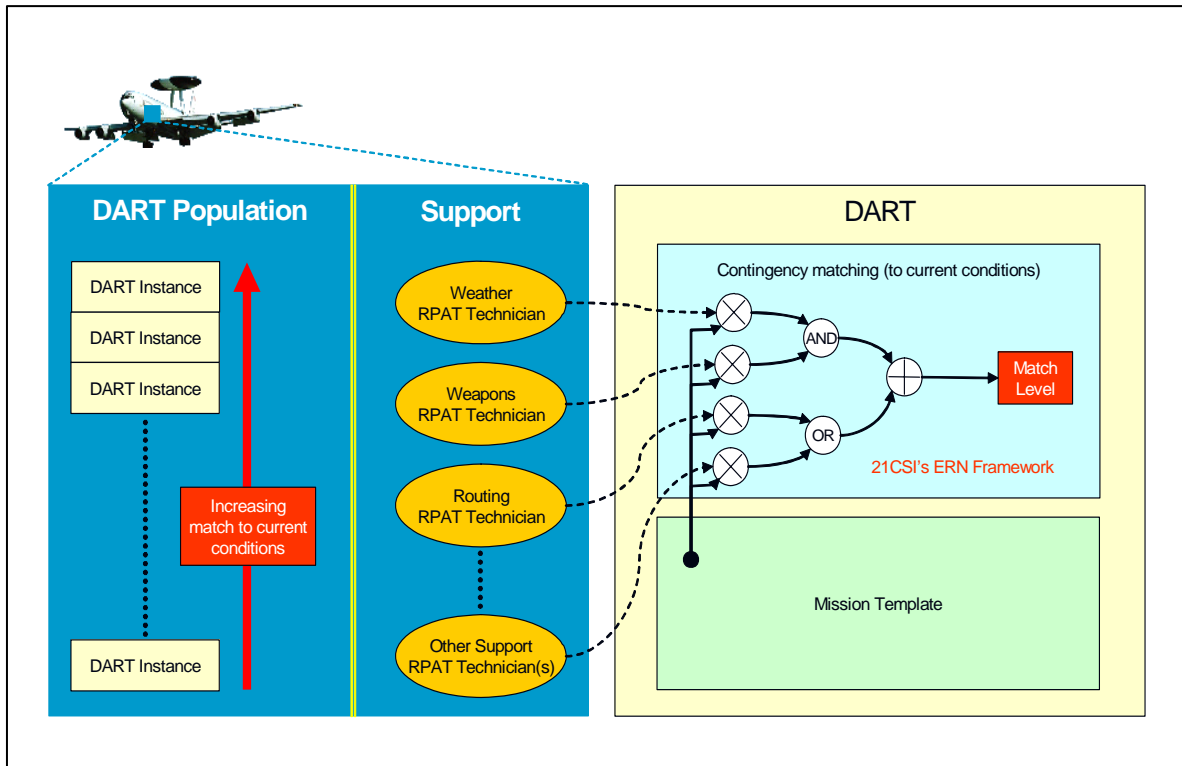
Figure 1 - DART Technician Architecture

a response to TST opportunities as possible, and thus it is key for the DART to keep its decision state in sync with the incoming real-world data, as much as possible.

From the general process, the notational structure of the DART is laid out in Figure 1. First, in order to aid rapid evaluation, the "partial evaluation" concept has been applied. If one DART was paired with one TST type, a significant level of intelligence (and processing power) for evaluation would be required. Instead, we will use a many-to-one relationship for DART-TST pairing. At each point where a decision may need to be made, a split to two or more DARTs can occur. The pre-conditions for each of these DARTs can then be pre-calculated, meaning that only a simple check need occur during the time-critical phase of selecting a DART for situation response. However, it should be noted that simply splitting at every decision point will cause an exponential growth in the number of DARTs in the system. Therefore, a method is required to balance the total number of DARTs versus the time and information gained by pre-processing. Data on the constraints is gathered by specific Technicians and provided to the various DARTs in the system. Each of these DARTs store in their mission template the specific constraints they must match as well as the relative importance of each condition. This data is combined together using 21CSI's ERN (Evidential Reasoning Network) subjective logic framework (subjective logic uses the same concept as fuzzy logic with an additional uncertainty component) resulting in an estimation of any given DART's match to current conditions. When a TST appears, the DARTs will have been prescreened for appropriateness saving computation time during this time-critical period.

You can see in Figure 1, instances of the DARTs represent the spectrum of anticipated targets and situations. They obtain updates on the current operational situation from other Technicians and evaluate how closely they match. This match entails analysis of weapons and aircraft available as well as environmental concerns such as weather. DARTs that are a poor fit are rated lower and shifted further down the population list. This continual updating ensures that when a TST does appear, the best choices can be presented to the user rapidly from the top of the list. The selection process then involves adapting the mission template and finalizing any details such as weapon assignment and recommended flight paths.

Initial Prototype

After constructing an overall design idea, particular elements were chosen for implementation into the initial prototype. To limit the scope, we elected to concentrate on the airborne segment of the system. Specifically:

- Implement selection of DART and go/no-go decision by user

- Changing of operational situation over time

    o Ex: Target moving near and through a no-fire-zone

- Implementation of DART

    o Hand crafted (since creation would normally take place at ground segment)

    o Retrieves updated situational data and re-rates accordingly

The prototype was created using Eclipse and 21CSI's AEDGE toolkit. The DARTs and Technicians were built with the JBOSS Rules engine. The DARTs utilized 21CSI's ERN subjective logic framework to maintain logical consistency in the face of uncertainty when generating DART-to-situation match ratings. 21CSI's internal simulator was used to create and update the test scenarios that were run through the prototype.

Screenshots of the prototype in various stages of execution are included below. Figure 2 is a brief overview of the user interface elements. On the left is the scenario map, showing the state and position of the various elements of the scenario including assets, contacts and AOIs. On the right side of the screen is the list of active DARTs, sorted by their rating. An at-a-glance summary of their rating is given to the left of their names in a stoplight format (green/yellow/red). Each DART can be expanded to show some of the underlying information used in generating their rating. Examples include weapon suitability ("WEAPON"), intended TST type similarity ("TST") and lack of violations of the rules of engagement ("ROE").
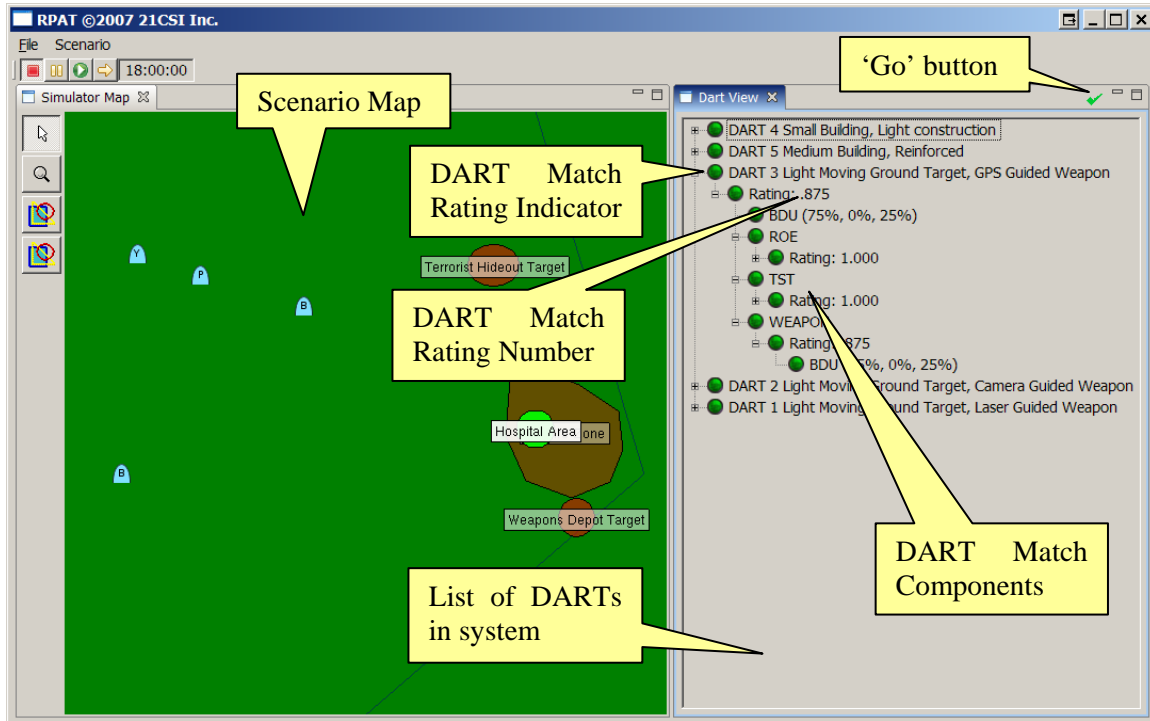
Figure 2 - UI Overview

Figure 3 shows the start of the demonstration scenario. To the east, there is an AWACS aircraft along with its escort maintaining a position. Additionally, there are two aircraft on ground attack missions. The northern aircraft, "Bomber 2," has been assigned to
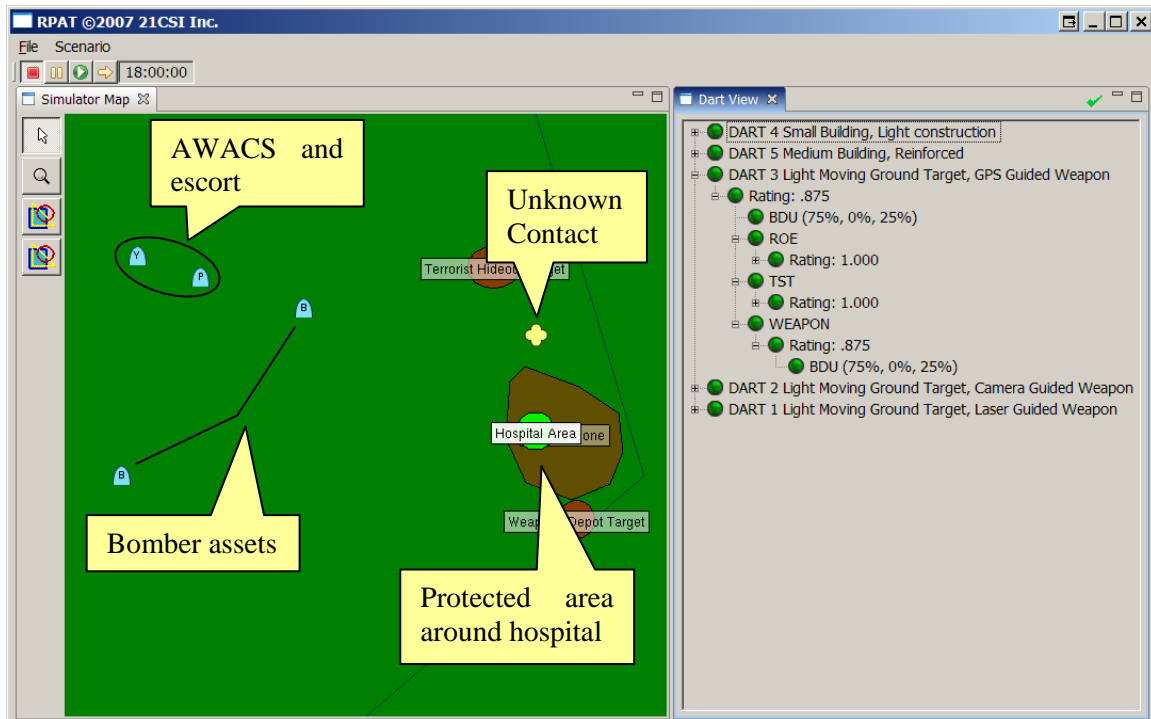

Figure 3 - Scenario at start of simulation

destroy a terrorist hideout in the north-eastern portion of the area. The other (southern) aircraft, "Bomber 1," is out to destroy a weapons depot in the south-eastern portion of the area. A "no fire zone" has been designated around a local hospital. Finally, just north of the hospital, an unidentified truck has been spotted moving south-west. Note that at this time, all DARTs are rating themselves as a good match ("Green") because they all have the resources necessary to execute their built-in missions and no TST has been identified for them to attack yet.

If we allow the scenario to proceed for 19 seconds, the result is shown in Figure 4. The primary change is that the unknown contact has been reclassified as a TST. Now that they have a target, the DARTs have begun re-rating themselves as well as selecting resources to attack the TST. Immediately, DARTs 4 and 5 notice that their building attack missions have no relevance to hitting a truck so they down-rate themselves to the bottom of the list ("Red"). DART 3 rates itself highly ("Green") against this target at the moment. DART 2 is somewhat lower ("Yellow") because the only camera guided weapon it can find has a warhead that is significantly larger than necessary and may cause excessive damage to the surrounding area. Curiously, DART 1 has rated itself lowly ("Red"). To see why, we expand it out and see that it believes it would violate the ROE. Looking closely, by the time its desired platform, "Bomber 1," could reach the target the target will have entered the no fire zone. Thus, we see that it makes sense for that solution to be rated low at this time.

Moving forward a couple of seconds to Figure 5, we see that all three DARTs have been down-rated for the same ROE reason. Because we delayed a number of seconds in making a decision, we now have no viable plan of attack. Waiting a good deal of time, Figure 6 shows the TST as it begins to emerge from the protected zone and we can again
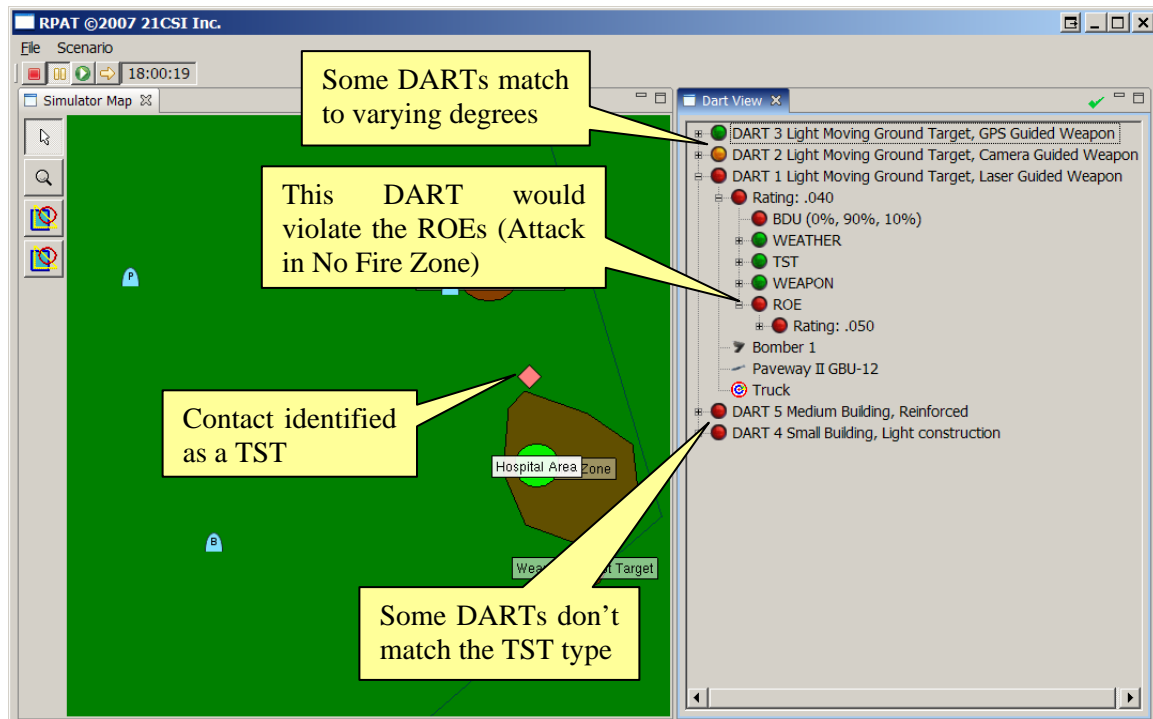

Figure 4 - TST Appears, DARTs generate (and rate) COAs

assign various plans of attack. DART 1 is approved as the COA against the TST and "Bomber 1" is redirected against the target.
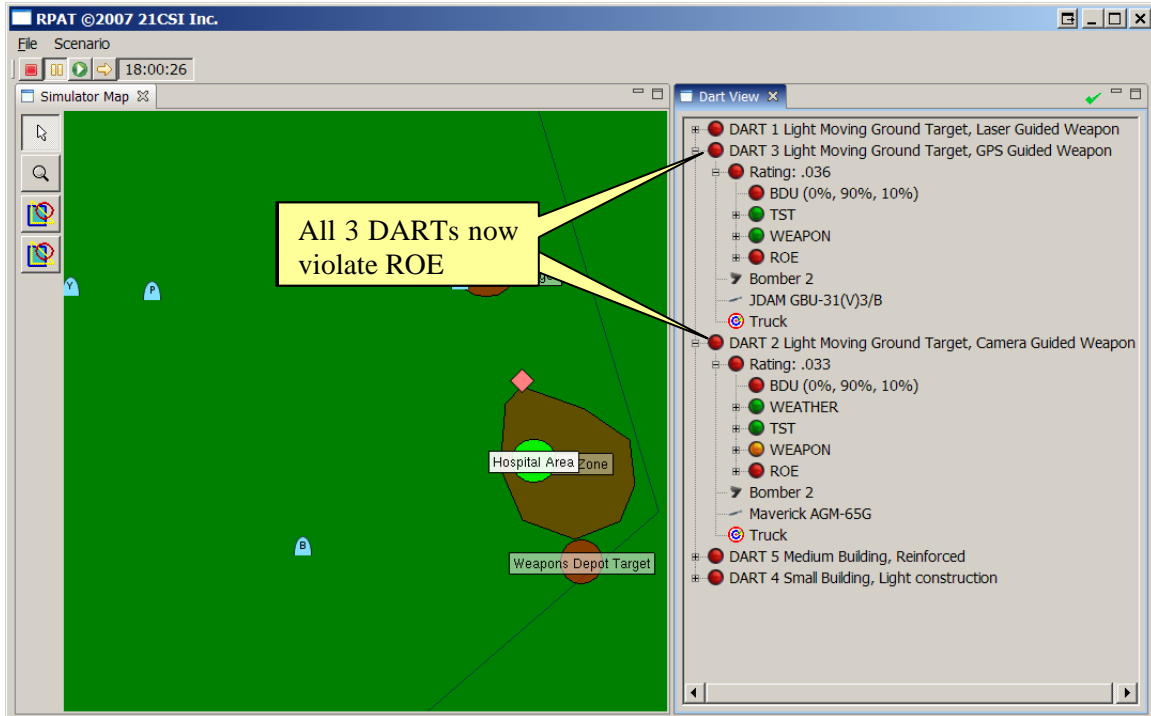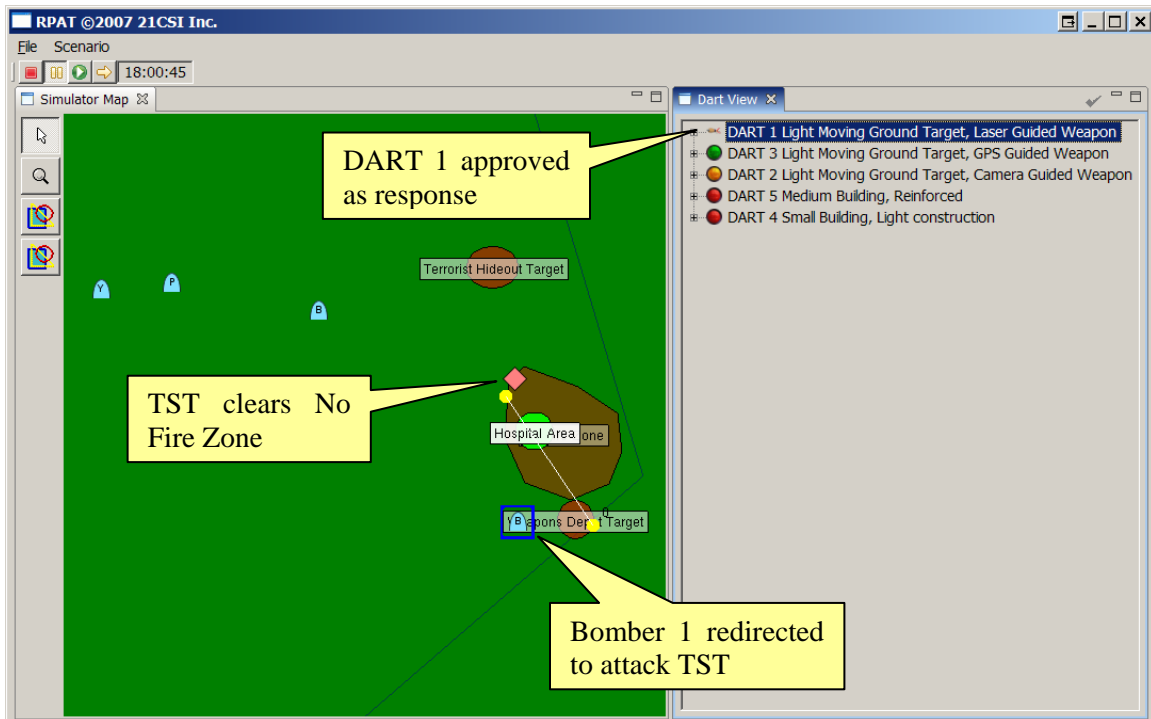

Figure 5 - All three (1-3) DARTs violate ROE

Figure 6 - TST clears protected zone, DART 1 selected as response

Future Work

The initial investigation into TST methodology and current practices helped to generate innovative ideas and directed the design of the RPAT Technicians system. Investigation into previous systems showed that encoding TST processes into rules systems was feasible. This allowed us to focus on the other half of the problem, evaluating those rules in a short amount of time, and lead to the design of the DART. The initial prototype was constructed to show the DART population in action and demonstrate the feasibility of evaluating that population with reasonable computational resources. Our efforts have demonstrated the technical feasibility of our approach. Our effort has given us a head-start on future work and significantly reduces the technical risks because we have a more developed basis on which to build.

The innovation for the next phase of work will arise from the completion of the DART life cycle. In the system design, it was determined that DARTs would be created in the AOC, applying TST procedures and utilizing AOC resources to determine what impacts they might have if executed. Then, these DARTs would be shipped up to the C2 platform ready to provide their specific plans and knowledge when the situation warrants. In initial research, software was discovered that could apply TST procedures in a semi-automated fashion, solving the need to prove feasibility for this portion of the DART cycle. Thus, the initial effort became focused on the latter half of the cycle.

For a complete prototype to be developed, though, the creation half of the DART life cycle must be addressed. This can happen either through the integration of a pre-existing "TST solver" or a custom solution, depending on the needs determined at design time. However, this alone does not solve the problem. In addition to the creation of "TST attack plans," we will need a mechanism to determine when such a plan must be split into two DARTs. Recall that a DART consists of a set of initial conditions (weather, etc.) and a mission plan. In order to keep each DART focused on its particular solution, it may be necessary to have multiple DARTs to cover all eventualities and solutions. This can be taken too far however, resulting in many DARTs with only trivial differences. An algorithm is required that can balance between these two extremes. To solve this problem, we intend to adapt an algorithm from data mining, decision tree induction. This algorithm creates trees from data sets by repeatedly partitioning the data set based on informational gain. This is very similar to our needs; however, we must replace informational gain with what we might term "operational gain." Thus altered, we will be able to build populations of DARTs that maximize coverage while minimizing the overall number.

Finally, we expect this process to be useful for more than just rapid TST response. We intend to apply the same techniques to other situations where speed is a concern, such as emergency response. Ideally, emergency planners could use their test and training scenarios as input to the system. The DARTs created will use these as a guide and when emergencies call for recommendations, the user will be able to select options based on pre-approved actions but modified to match the current situation.

With the next iteration of the RPAT Technicians prototype, we expect to showcase what will become a revolutionary new tool to support rapid decision making without usurping human responsibility or initiative.

Conclusion

The RPAT Technicians system aims to address the need of Air Force leadership to respond in a timely manner to targets of an unpredictable and fleeting nature. It uses the concept of Technician agents and specifically the DART, or Decision Agent for Rapid TST, to provide processing intensive analysis while still achieving near-instant response when the time comes. The DARTs update themselves continuously to adapt to the changing situation and rate themselves depending on how appropriate they for the current situation. At the action point, when a recommendation is need, candidates are presented starting with those rated highest. Each candidate is modified from tentative form to exactly meet the current requirements and the user supplies the final judgment. A prototype was created to demonstrate the process during the time surrounding the action point. This proves the feasibility of the system for responding to events in short amounts of time.

In the future, we plan to expand the prototype to include the automated creation of DARTs from resources with long time delays or that are computationally intense. Additionally, we wish to explore the application of these techniques to other areas requiring rapid decision support such as emergency management.

Overall, we feel the RPAT Technicians system has already shown promise after initial work which will only increase with further development.

References

Barnes, L. R. Elliott, P. Tessier, and P. V. Petrov, 2002. Distributed Command and Control Research: Networking Multiple Simulation Platforms. Paper presented at Seventh International Command and Control Research and Technology Symposium in Monterey.

Chaiken, S., L. Elliott, M. Dalrymple, S. Schiflett, M. Coovert, D. Riddle, T. Gordon, K. Hoffman, D. Miles, and T. King. 2001. Weapons Director intelligent agent-assist task: Procedure and findings for a validation study. Paper presented at International Command and Control Research and Technology Symposium, June.

Elliott, L. R., S. Chaiken, A. Stoyen, P. Petrov, and D. Riddle. 2000. An Agent-Enabled Simulation and Training System to Support Team-based C3 Performance Research. Presented at 5th Conference on Naturalistic Decision Making, May 26-28, in Tammsvik, Sweden.

Elliott L., C. Barnes, L. Brown, J. Fischer, J. Miller, M. Dalrymple, J. Whitmore, and R. Cardenas. 2002. Investigation of Complex C3 Decisionmaking under Sustained

Operations: Issues and Analyses. Presented at Seventh International Command and Control Research and Technology Symposium in Monterey.

Hura, Myron. 2002. *Enhancing Dynamic Command and Control of Air Operations Against Time Critical Targets*. RAND Publishing.

Han, J. and M. Kamber. 2001. *Data Mining: Concepts and Techniques*. San Diego: Academic Press.

Hatcliff, J., T. Mogensen, and P. Thiemann (eds.). 2000. *Partial Evaluation. Practice and Theory*. Springer.

Haffa, Robert P. Jr. and Jasper Welch. 2005. Command and Control Arrangements for the Attack of Time-Sensitive Targets. Nov.

Jøsang, A. A Logic for Uncertain Probabilities. 2001. In *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems* 9: 279 – 212.

Multi-Service Tactics, Techniques, and Procedures. 2004. TST Multi-Service Tactics, .Techniques, and Procedures For Targeting Time-Sensitive Targets. April.

Ratliff, W., and M. Gerard M. Reducing Time Sensitive Target (TST) Prosecution Decision Time using Inference Processing and Intelligent Agents.

Stoyen, A., L .Walrath, S. Schiflett, L. Elliott L. and M. Dalrymple. 1999. Situational awareness measurement in AWACS Weapons Director teams. Presented at the 4th Annual Symposium, June 8-9, in Piney Point, MD.